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ORIGINAL PAPER

GIS based land suitability assessment along Laos- China border

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Abstract: Assessment of the forest land use change and proposed land suitability for tea for the area along Laos – China Border were the main purpose of this research paper. An integrated GIS-based analysis system (IGAS), supporting assessment of forest land-use and land suitability for the study area where along Laos-China border was developed. Multi criteria analysis and system dynamics techniques were used to assess forest land use and land suitability and to forecast potential land-use for tea. The total study area is estimated at 10 325.07 km^2 according to the field data collection and data analysis. The area of current forest cover decreased rapidly from 6337.33 km^2 (61.38%) in 1992 to 5106.28 km^2 (49.46%) in 2002 in the study area. The current forest was mainly transferred to potential forest and permanent agriculture especially to rubber plantation areas even in the National Conservation Biodiversity Conservation Areas. The main causes of forest land use change are poverty. In order to address the problems, land suitability classification for tea was developed based on the multi-criteria. And finally two options of land suitability classification for tea for the study areas were developed.

Keywords: Forest; Land evaluation; Phongsaly; Laos; Tea

Introduction

Laos is characterized by mountainous and hilly terrains that account for 85.5% of the total area of the country and the remaining approximately 15.5% area is occupied by plains. Pressure on land resources and the recognition by scientists of the importance of land to mankind and the world have recently led to further exploration of land resources and their rarity (Drohan and Farnham 2006). Moreover, with economic development, the percentage of conversion of forest land to agricultural plantation land use has been increasing during the last 15 years. Thus, an outstanding issue of food security and ecological safety is urgent and there is a need for more research on the relationship between land utilization and grain production as well as ecology security. Since the 1980s, land suitability evaluations conducted in the Northern Laos have emphasized on quantification and precision aspects and it was conducted in the northern part of Laos where the slash and burn cultivation areas were popular.

In this analysis, remote sensing (RS) technique in combination with geographical information system (GIS) was used. As a result of using this methodology, consistent with the guidelines of the FAO framework for land evaluation, research on the evaluation of land suitability has become more up to date, quicker, and more efficient (Meng 2005; Chen et al. 2002; Zhang et al. 2003). Foley et al. (2005) reviewed the global consequences of land use and their review indicated that although modern land use practices increased the short-term supplies of material goods, they might undermine many ecosystem services in the long run. Thus, land suitability evaluations need to be performed to ascertain the optimum area necessary for food production and forest stands. However, solutions to difficult and complex problems associated with the increased scope for use of land resource and its management will not be found within one discipline. Development and promotion of evaluation of land suitability requires an interdisciplinary system approach, rather than just a multidisciplinary approach. Information obtained from the Land Use/Cover Change (LUCC) Project, which is a core project of the International Global and Biology Plan (IGBP), was used in this study.

LUCC studies are designed to improve the understanding of the regional dynamics of change in land use and land cover, with the focus being on improvements in the ability to predict such a change (Turner II et al. 1997). RS and GIS can improve and facilitate these studies (Asanzi et al. 2006). The integration of land evaluation, LUCC, RS, and GIS can provide an improved basis for addressing land use problems. Interactions between the interdisciplinary components of agriculture and land systems are generally very important (Ahuja et al. 2006; Quan et al. 2006b).

However, few studies have reported on the combined use of LUCC and land evaluation for the analysis of land problems in

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southeastern China (Quan et al. 2006a). Consequently, on the basis of the RS and GIS techniques, this study evaluated the forest land use change and from 1992 to 2002 in the six districts within three provinces along Laos-China Borders and land suitability classification were proposed in this research in order to address the land use change and also poverty eradication and this topic is also very importance for providing a scientific basis for decision-making on sustainable use of land.

Material and Methods

Study area

The study areas are consisted six districts (Fig. 1) namely: Yot-Ou, Boun-Nua, Sing, Bountai, Namtha and Namor within three provinces namely: Phongsaly, Oudomxay and Loung Namtha which located in the northern part of Laos and it has the long boundary with Xishuangbanna Yunnan China. The study area is with land area of 10 323.67 km^2. The topographical features are complex and varied and are dominated by mountains and hills. It can be classified as Cwa climate; a Temperated, dry climate with the warmest month above 22°C such as Yunnan Province, China

Fig. 1 Study area

Forest and land use assessment method

Forest and land use classification were applied based upon FAO recommendation that was worked out by Prof. Dr. Jozsef Fidlocsky in 1987. A minor revision was made in 1990 at the start of the National Forest Inventory, mainly in order to make it adapted to ground survey. At the same time, the land use classes were put together into 6 main land use groups.

Definition of forest land use classification

Current Forest: Current Forest includes natural forests and forest plantations. It is used to refer to land with a tree canopy cover of more than 20% and area of more than 0.5 ha. The trees should be able to reach a minimum height of 5 m. The basis for the distinction between forest and other land use groups is the crow density. In this study the natural forests are classified into forest types which compose Upper and Lower Dry Evergreen Forests, Upper and Lower Mixed Deciduous Forests, Gallery Forest, Coniferous Forest, Mixed Broadleaved and Coniferous Forest, and Dry Dipterocarp.

Potential Forest: Previous forest areas where the crown cover has been reduced below 20% for some reason (logging or shifting cultivation) are classified as Potential Forest. The potential forest includes Bamboo, Old shifting cultivation areas (young secondary forests) and Temporary Unstocked areas.

Other Wooded Areas: Other wooded areas are defined as areas with a certain cover of trees or shrubs but being unsuitable (too poor) for forest production. The tree covers is less than 20% (if it would be more it should considered as current forest).

Permanent Agriculture: Permanent agriculture include area for production of crops, fruit trees etc. and areas permanently being use for grazing

Other Non-Forest: Other Non-Forest Areas are the areas with other land use include land that for various reasons is "non-productive" and areas being used for other purposes than agriculture and forestry.

Water: The group water includes natural or artificially made areas of water.

Data collection and analysis

In order to estimate the directions and magnitude of forest land use changes in the study areas, former GIS data of forest land use change in 1992 and 2002 which obtained from Ministry of Agriculture and Forestry (MAF) used to extract the changes information of forest land cover during the last 10 years (see Fig. 2).

The forest land use datasets of the study areas (1:50,000) in 1992 and 2002 were from Agriculture and Forestry Lao PDR (MAF). Forest land use change assessment was conducted by MAF, plot sampling on Satellite Images Maps (SIMs) to detect the changes of land use in 1992 and 2002 for the study area and field verification in order to identify causes of the changes. Then, the dynamic information of the land cover change during 10 years was calculated by the map algebra in ArcGIS 9.3 software. In this study, the data sets were reclassified into five categories, including current forest, potential forest, permanent agriculture and other non-forest. See Table 3. Map of land use in the study areas for 1992 and 2002 produced from Landsat images were shown in Fig. 2.

The dynamic information of the Land use change during 10 years was calculated by the map algebra in ArcGIS9.3. According to the principle of map algebra, we can calculate any two period of Land use category figure that may be named by A^k and A^{K+1}. The equation is as follows where the number of Land use category should be less than 10.

$$C_{ij} = A_{ij}{}^{k} \times 10 + A_{ij}{}^{k+1} \qquad (1)$$

According to Eq. (1), we can get the Land use change figure that can be named C_{ij} from the period k to period k+1. The figure C_{ij}

can show the Land use change and change distribution. Using this method we gained the transferring matrix that reflects the quantitative transferring relation between different Land use categories in the study area (Table 4).

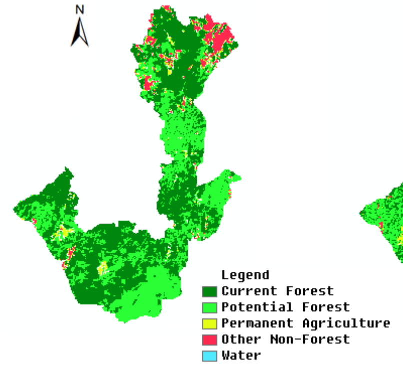

Fig. 2. Forest land use change from 1992 (left) to 2002 (right) in the study area

Procedure and methodology in land suitability

The general process for land-use suitability analysis is shown in Fig 3. In this process, land-use types were selected based on local farming practices, opinions of farmers, scientists, and local district and province leaders. Land-use requirements are necessary conditions to adopt a land-use type reasonably. Therefore, investigating and determining land-use requirements for each land-use type are essential and basic for evaluating land-use suitability for each land mapping unit. Each land-use requirement could be organized in form of one map layer in GIS. The overlay of these map layers in GIS produces a composite map of land mapping units. Each land mapping unit is an area which has common land-use characteristics. Sustainable evaluation of land-use suitability requires evaluating not only natural physical conditions but also socio-economic and environmental conditions.

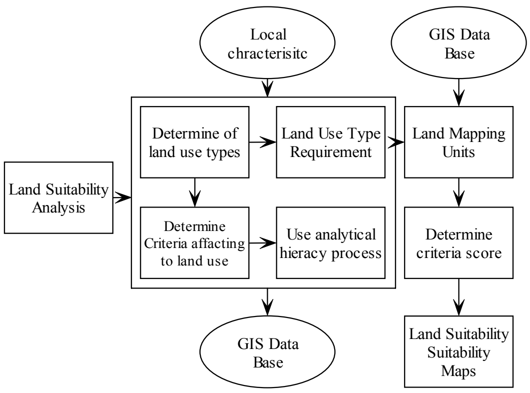

Fig. 3 Land-use suitability analysis process

In order to determine which criteria (and at what levels or weights) affects the land-use suitability for study area, Delphi method is used to design and evaluate factor of tea planting and weight of these factor by the experts. Using analytical hierarchy process technique these judgments on important of criteria were converted to weight of evaluation factors. Score for each criteria on each land mapping unit was then determined.

Analytical Hierarchy Process technique (AHP)

AHP is a kind of evaluation method. For the basic principle of AHP, first is to find out relative factors about a complicated environmental problem, and to make sure of their hierarchies, then to make certain of comparative significance by comparing these factors each others, and finally give their weights (Wen et al. 2000; Fan et al. 2000). The AHP has three basic steps. It begins by decomposing the overall goal (Suitability) into a number of the evaluation factor and the sub-factor. The goal itself represents the top level of the hierarchy. Major factor comprises level two, sub- factor makes up level three, and so on. Applying this step to land-use suitability analysis, decision criteria relevant to our goal were identified and arranged in the hierarchy illustrated in Fig. 3 and Table 1.

Table 1. Evaluation factor for tea plantation

Evaluation factor	Class value range	Grade	Model 1	Model 2
Elevation(m)	1000-1400	1	100	100
	500-1000 or 1400-1600	2	80	80
	250-500 or 1600-1800	3	60	60
	<250 or >1800	4	50	50
Gradient(°)	15-25	1	100	100
	25-35	2	85	85
	6-15	3	60	60
	>35 or <6	4	unsuitable	unsuitable
Direction of slope(°)	45-135	1	100	100
	30-45 or 135-180	2	85	85
	180-330	3	60	60
	0-30 or 330-360	4	unsuitable	unsuitable
pH value of land	4.5-5.5	1	100	100
	4-4.5 or 5.5-6	2	85	85
	6-6.5	3	60	60
	<4 or >6.5	4	unsuitable	unsuitable
Soil depth (m)	>100	1	100	100
	75-100	2	85	85
	<75	3	unsuitable	unsuitable
Annual mean precipitation (mm)	1400-1700	1	100	100
	1700-2000	2	85	85
	900-1400 or 2000-2500	3	60	60
	<900	4	unsuitable	unsuitable
≥10℃ Accumulated temperature (°C)	>4500	1	100	100
	4000-4500	2	85	85
	3700-4000	3	60	60
	<3700	4	unsuitable	unsuitable
Current land use type	Potential Forest	1	100	--
	Permanent Agriculture	2	20	--
	Current Forest, Other Non-Forest, Water	3	unsuitable	--
Distance from the Village (km)	<3	1	100	--
	3-6	2	80	--
	6-9	3	50	--
	>9	4	30	--
Distance from the border checkpoint (km)	<20	1	100	--
	20-40	2	80	--
	40-60	3	60	--
	>60	4	40	--

Weight value of evaluation factors

The higher the suitability index value for a particular land use, the greater is its suitability. When restrictions were imposed on a particular land use, the class index value assigned was zero, which indicated that it was unsuitable, see Table 1. Different evaluation factors have different effects on land suitability. Therefore, it is necessary to determine the weight value that each evaluation factor has on land suitability. In this study, the analytical hierarchy process (AHP) was used and expert advice was obtained to determine the weight value of each evaluation factor for tea garden, see Table 2

Table 2. The weight values of evaluation factors for tea plantation

Evaluation factor	Model1	Model2
Elevation (m)	0.12	0.20
Gradient (°)	0.09	0.15
Direction of slope (°)	0.07	0.12
pH value of land	0.13	0.22
Soil depth (m)	0.09	0.14
Annual mean precipitation (mm)	0.06	0.10
≥10℃ Accumulated temperature (°C)	0.04	0.07
Current land use type	0.19	--
Distance from the Village (km)	0.10	--
Distance from the boder checkpoint (km)	0.11	--

Determination of land suitability grade

The size of the grid cell for each factor overlay was 30 m by 30 m. The determination of the land suitability grade was done using the index sum method. This method sums up the product of weight values and gradation index value for all evaluation factors and for each evaluation unit using the following equation:

$$F = \sum_{k=1}^{n} w_{\mathrm{ik}} \times U_{ik} \tag{2}$$

where F is the sum total of fraction values for every evaluation unit, W_{ik} is the weight value of the k evaluation factor for the i evaluation unit, U_{ik} is the index value of the k evaluation factor for the i evaluation unit, and n is the number of evaluation factors.

Results and discussions

Land use change during 1992–2002

The overall land use change in 1992 and 2002 were showed in Table 3 and 4. According to the Tables 3, Current Forest and Potential Forest were two largest Land use category in the study area, both in 1992 and in 2002. Current Forest accounts for 61.38% in 1992 and 49.46% in 2002 of the total area, and Potential Forest was 31.55% and 45.28% of the total area in 1992 and 2002, respectively. From Table 3 we can see that the areas of Potential Forest, Permanent Agriculture and Water increased from 1992 to 2002. On contrary, the areas of Current Forest Other Non-Forest decreased.

Table 3. The land use during 1992 and 2002

1992			2002		
Land use type	Areas (km^2)	%	Land use type	Areas (km^2)	%
Current Forest	6337.33	61.38	Current Forest	5106.28	49.46
Potential Forest	3257.84	31.55	Potential Forest	4675.27	45.28
Permanent Agriculture	131.91	1.28	Permanent Agriculture	311.38	3.02
Other Non-Forest	596.59	5.78	Other Non-Forest	230.29	2.23
Water	1.40	0.01	Water	1.85	0.02
Total	10325.07	100.00	Total	10325.07	100.00

The most notable changes of land use in the study areas were declined in Current Forest and an increase in Potential Forest and Permanent Agriculture. In 1992, the area of Current Forest was about 6337.33 km^2, with a proportion of 61.38% in the study area, but by 2002, the total area of Current Forest was estimated to be 5106.28 km^2 and the proportion decreased to 49.46%. The annual rate of decrease slowed down from 1.1% per year during 1992–2002. Meanwhile Potential Forest increased from 3257.84 km^2 in 1992 to 4675.27 km^2 in 2002, with annual growth rate of 1.3% (Table 3). Permanent Agriculture Land increased in size from 131.91 km^2 in 1992 to 311.38 km^2 in 2002.

Table 4. Forest land use matrix

	Land Use Type	2002 Current Forest	Potential Forest	Permanent Agriculture	Other Non-Forest	Water	1992 Total
1992	Current Forest	4154.01	2072.05	83.6775	27.2259	0.3618	6337.33
	Potential Forest	891.602	2250.09	104.094	12.0519	0	3257.84
	Permanent Agriculture	1.8396	7.938	121.75	0.1845	0.20	131.91
	Other Non-Forest	58.7295	345.169	1.8621	190.83	0.00	596.59
	Water	0.0954	0.0216	0	0.00	1.2825	1.40
	2002 Total	5106.28	4675.27	311.38	230.29	1.85	

The considerable decrease in Current Forest and the concomitant increase in Potential Forest and Permanent Agriculture

Land resulted from many factors namely: high demand for wood and Non-timber forest products in the markets of wood deficient neighboring countries and countries in the region as well as the imposition of logging bans in some neighboring countries about high pressure on forest resources in Lao PDR, shifting cultivation practices, opium poppy cultivation (NAFRI and CIRAD 2003) and forest fires are still the main causes of land use change particularly in the study areas. Results of the transition matrix in Table e4 indicated the area increase or decline of each land use category.

Proposed land suitability for tea plantation

Six districts within three provinces were selected as study area namely: Boun-Nua, Namor, Yot-Ou, Sing, Namtha, and Bountai. The result of forest land use assessment has already mentioned to the land suitability for tea plantation, for addressing the forest land use change and helping the local people to increase their income from tea and sustainable use of the land (Chanhda 2007). The land suitability for the study area was classified into four grades namely: highly suitable area, moderately suitable area, marginally suitable area and not suitable area. Two model of land suitability for tea plantation were developed for the study areas.

eTen factors were selected to calculate the land suitability for tea namely: elevation, gradient, direct of slope, pH value, soil depth, annual mean precipitation, accumulate temperature, current land use, distance from the village, distance from the Laos-China border checkpoint.

All factors were selected to calculate the land suitability for tea in the model 1, while only 7 factors of land suitability for tea were selected in the land suitability for tea model 2. The factors were selected are: elevation, gradient, direct of slope, soil depth, annual mean of precipitation, accumulative temperature. The result of land suitability for tea model 1 was explained in the Table 3 while model 2 was explained in the table V. The definition of land suitability in this research was explained below.

Grade I: Highly Suitable
Land having no significant limitations to sustained application of a giving use, or only minor limitation that will not significantly reduce productivity or benefits and will not raise inputs above an accepted level.

Grade II: Moderately Suitable
Land having limitations which in aggregate are moderately server for sustained application of a giving use, the limitations will reduce productivity or benefits and increase required inputs to the extent that the overall advantage to be gained from the use, although still attractive, will be appreciably interior to that expected on grade I.

Grade III: Marginally Suitable
Land having limitations which in aggregate are serve for sustained application of a given use and will so reduce productivity or benefits, or increase required inputs, that this expenditure will be only marginally justified.

Grade IV: Not Suitable
Land which has requires that appear to preclude sustained use of kind under consideration. And land which has not been assessed for given use, because the application of the use to that area is precluded by the initial assumptions of the evaluation.

Land suitability for tea plantation (model 1)

Model 1 was evaluated land which is under consideration for require of tea plantation, and considerate for land assessment and local condition. The final land suitability for tea planting for the model 1 is shown the Fig. 4 and Table 5. It is about 9751.19 km^2 and covered 94.4% of the total land areas. For the grade I or most suitable is 321.47 km^2 and covered 3.11% of the total land area and The area in Yot-Ou District, Phongsaly province is the main suitability areas for tea plantation when comparing with other districts.

For the land fall into grade II which is moderate suitable for tea is 227.72 km^2, and covered 2.20 % of the total land area and Yot-Ou District, Phongsaly Province were the main suitable area, while land suitable grade III which is suitable for ea is 25.20 km^2 and covered 0.24% of the total land area. Sing District is the main suitable land area this grade.

Land suitability for tea plantation (model 2)

Model 2 was evaluated land which is under consideration for requirement of tea plantation. The unsuitable land area for tea growing is 8681.64 km^2 and covered 84.08% of the total areas Table 6 shows area of every Grade, based on Land Suitability tea plantation of Model 2. Fig. 5 is map of Model 2. The area which fall into grade I is increased when comparing with model I, because only 7 factors were used to calculate the suitable land for environment of tea plantation. The main area of the most suitable land for tea growing is located in Yot-Ou District, Phongsaly Province, while the main suitable land for tea growing in the grade II is located in the Sing District, Loung Namtha Province

Conclusions

To make the maximum beneficial use of land for a certain area, a planner should take into consideration the actual forest land use and land suitability. This will allow the accuracy and implementation of basic information to be improved and then applied in the planning process. An important goal in forest land use and land suitability evaluation is to provide assistance to policy makers, planners and developers in the optimal development of an area while preserving the environment. The evaluation results can assist planners in making decisions on land-use alternatives for specific land parcels.

The GIS methodology is capable of providing a degree of accuracy in assessing the potential suitability of land parcels for sustainable of forest land use. To make the maximum beneficial

use of land for a certain area, a planner should take into consideration. This will allow the accuracy and implementation of basic information to be improved and then applied in the planning process. The application of such a GIS technology has demonstrated that most operations can be accomplished efficiently and cost-effectively. The functional capabilities of GIS software support the development of spatial forest land use evaluation for land suitability planning purpose.

Table 5. Land suitability tea plantation Model 1

Region	Grade I		Grade II		Grade III		Unsuitable		Total area (km^2)
	Area (km^2)	Percentage of total area (%)	Area (km^2)	Percentage of total area (%)	Area (km^2)	Percentage of total area(%)	Area(km^2)	Percentage of total area (%)	
Yot-Ou	132.70	4.66	98.35	3.46	7.74	0.27	2607.92	91.61	2846.72
Boun-Nua	33.82	2.76	8.51	0.69	1.46	0.12	1182.90	96.43	1226.69
Bountai	44.30	3.45	12.84	1.00	0.31	0.02	1227.69	95.53	1285.14
Namor	29.89	1.96	13.17	0.86	0.29	0.02	1484.91	97.16	1528.26
Namtha	32.53	1.51	15.13	0.70	2.42	0.11	2098.36	97.67	2148.44
Sing	48.23	3.74	79.20	6.14	12.98	1.01	1149.41	89.11	1289.82
Total	321.47	3.11	227.21	2.20	25.20	0.24	9751.19	94.44	10325.07

Table 6. Land Suitability tea plantation Model 2

Region	Grade I		Grade II		Grade III		Unsuitable		Total area (km^2)
	Area (km^2)	Percentage of total area (%)	Area (km^2)	Percentage of total area (%)	Area (km^2)	Percentage of total area (%)	Area (km^2)	Percentage of total area (%)	
Yot-Ou	446.41	15.68	137.94	4.85	0.00	0.00	2262.37	79.47	2846.72
Boun-Nua	99.15	8.08	24.83	2.02	0.00	0.00	1102.71	89.89	1226.69
Bountai	151.64	11.80	65.43	5.09	0.00	0.00	1068.07	83.11	1285.14
Namor	85.81	5.61	44.15	2.89	0.00	0.00	1398.30	91.50	1528.26
Namtha	172.24	8.02	90.25	4.20	0.00	0.00	1885.95	87.78	2148.44
Sing	170.15	13.19	150.90	11.70	4.53	0.35	964.24	74.76	1289.82
Total	1125.40	10.90	513.50	4.97	4.53	0.04	8681.64	84.08	10325.07

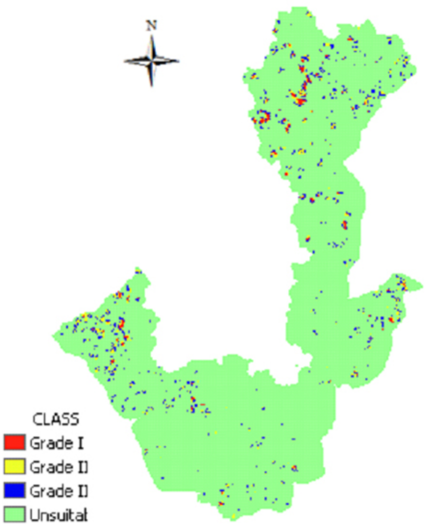

Fig. 4 Land suitability tea plantation (Model 1)

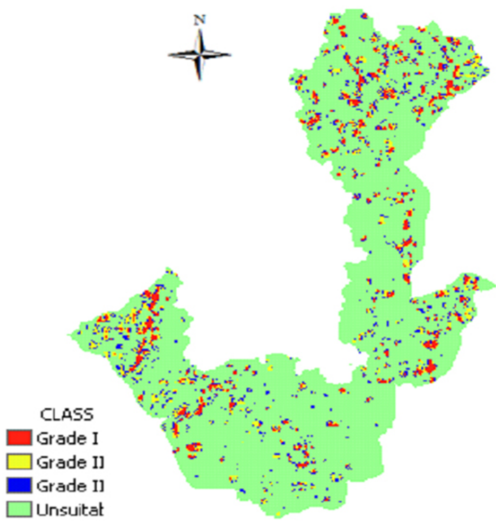

Fig. 5 Land Suitability Tea plantation (Model 2)

As a result of data analysis and field work analysis, there are a lot of rubber tree garden were developed around the study areas but there are only small tea garden were developed in the study areas. The tea garden was developed only in Phongsaly district, Phongsaly province while the other part of the study areas was not developed yet. The results of this paper showed that some part of each districts within the study area are suitable for tea growing.

So in order to address the forest land use change and poverty eradication for the study area, tea planting is also important for improving the economy and solving the poverty of the study areas.

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